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A REVIEW OF THE ACOUSTIC PROPERTIES OF NOISE BARRIERS MADE FROM WASTE AND PLANT-BASED MATERIALS

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Abstract. Noise barriers have been widely used around the world for many years. Solutions are being sought on how waste or plant-based materials can be integrated into the production of barriers, which would not deteriorate the acoustic properties of the barriers, and at the same time comply with the principles of circular economy and sustainability. The aim of the work is to review the currently conducted scientific research related to the development of new generation noise barriers and the use of waste or plant-based materials for their production, as well as to analyse the potential of these materials in acoustics. Materials and barriers made of construction and demolition waste, porous concrete made of waste, combustion bottom ash, tire waste, coconut fiber and straw, palm tree pruning waste, hemp fiber, bamboo was reviewed. The sound absorption and sound insulation properties of barrier constructions and materials are described. After conducting a review of the literature, the materials used for the production of noise barriers were determined, which correspond to the principles of the circular economy, as well as the general trends of structural solutions.

Keywords: Noise barriers, acoustic properties, sustainable materials, plant-based materials, recycled materials.

Introduction

With the expansion of urbanization, as the population increases, transport infrastructure is also developing rapidly. Noise is one of the main negative consequences of the expansion of transport infrastructure. For example, when assessing the health effects of noise from rail transport, there is a significant impact on poorer sleep quality, annoyance and the risk of hypertension resulting from these factors (Basner & McGuire, 2018; Clark & Paunovic, 2018; van Kempen et al., 2017; Guski et al., 2017; Nieuwenhuijsen et al., 2017; Śliwińska-Kowalska & Zaborowski, 2017; van Kamp et al., 2020).

Balnes et al. carried out an assessment in 2016 and found that noise causes at least 16,600 pathological deaths and 72,000 hospitalizations each year in Europe (Blanes et al., 2017). According to data from strategic noise mapping, it is estimated that 22 million inhabitants suffer from chronic annoyance caused by noise, and more than 6.5 million from chronic sleep disorders (European Environment Agency, 2020). At least 1 million years of healthy life are lost due to noise from transport. The reason for this is various sleep disorders, annoyance, exhaust heart disease, tinnitus and developmental disorders (World Health Organization [WHO], 2011, 2018).

Noise barriers are one of the most effective and widely used methods to ensure the reduction of noise from railways and road traffic (Ekici & Bougdah, 2003; Hanim Mohamed Ariff et al., 2022; Komkin & Nazarov, 2021; Nowoświat et al., 2018; Zaets & Kotenko, 2017). There are many types of noise barriers. Their choice in each situation is often determined by the position of the noise source, the noise emitted by the source, the atmospheric conditions and the terrain (Ekici & Bougdah, 2003). The effectiveness of the installed barrier depends on the materials used in the construction, the height of the barrier, the geometry of the surface, the shape, the acoustic properties of the additional elements installed on top of the barriers, the terrain and meteorological conditions (Grubeša et al., 2012; Laxmi et al., 2022; Watts, 2000).

The operation of noise barriers is based on the fact that a sound wave propagating directly through the barrier loses its initial energy and is attenuated. Part of the energy of the sound wave is reflected, the other part of the energy is absorbed and converted into heat energy. The rest of the sound wave's energy is transmitted and passes through the material or diffracted and reaches the receiver. Part of the diffracted, part of the transmitted sound wave energy can reach the receiver separately or together (Laxmi et al., 2022). The working principle

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of the noise barrier is shown in Figure 1. According to Watts, the sound diffracting edge of the barrier and the absorbing elements of the barrier determine the absorptive properties, while the geometry and shape determine the diffractive properties of the barrier (Watts, 2000). According to Astrauskas, one of the main parameters determining effective barrier screening is the variety of barrier forms (Astrauskas et al., 2021).

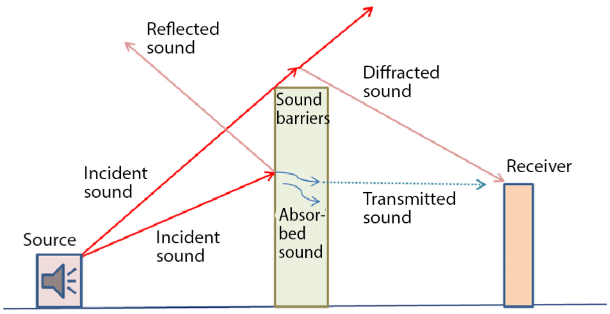

Figure 1. The principal scheme of noise barrier performance (Laxmi et al., 2022)

Noise barriers made of perforated panels and absorbent material are classified as sound-absorbing, barriers made of metal, plastic or brick are classified as sound-reflecting barriers (Astrauskas et al., 2021). Other types of noise-reducing barriers are also found in the literature: double, angular, hooded, longitudinal profile, green barriers, tunnels, soil embankments, etc. (Joynt, 2005). The classification of noise barriers according to their construction material, type of sound absorption and sound-absorbing material is presented in Table 1.

Table 1. Classification of noise barriers (Astrauskas et al., 2021; van der Stap & de Vos, 2013; Yoon & Pyo, 2019)

Material	Sound absorbtion	
	Type of sound absorbtion	Sound-absorbing material
Metal	Sound reflective	Mineral wool
Concrete	Sound absorbing	Glass wool
Ceramic blocks	With additional sound absorbing elements	Wood chips
Wood		Clay granules or ceramic granules
Transparent glass/ plastic		Plastic or rubber foam

Sound absorption and sound reflection parameters of noise barriers are important in designing and modeling barrier performance. The reflection of sound waves occurs when the energy of the sound wave is not fully absorbed and the sound absorption coefficient of the surface is equal to 0. In order to increase the efficiency of noise barriers, elements of various shapes are installed on the top of the structure, which improve the absorption properties. These elements are usually made of sound-absorbing, soft materials or sound-reflecting components. It was found that the highest efficiency is achieved by installing T-shaped profiles, Y-shaped profiles, arrow-shaped profiles, various branched shapes, U-shaped structures on the top of the barrier (Joynt, 2005).

Noise barriers made of concrete mixtures and wood chips, acrylic glass, polycarbonate, metal and synthetic materials have been widely used around the world for many years. Solutions are being sought on how waste or natural, plant-based materials can be integrated into the production of barriers, which would not deteriorate the acoustic properties of the barriers, and at the same time comply with the principles of circular economy and sustainability. The use of sustainable materials in the production of barriers would lead to lower energy consumption, would not harm the health of the population, and would allow them to be safely recycled or disposed.

The aim of the work is to review the currently conducted scientific research related to the development of new generation sustainable noise barriers and the use of waste or plant-based materials for their production, as well as to analyse the acoustic performance of these barriers and materials.

1. Methodology

The study used search in websites which provides access to a large bibliographic database, such as Elsevier, ResearchGate, Google Scholar, Applied Acoustics. While searching the aforementioned resources, the descriptors used during research included noise barriers, waste materials, plant-based materials, sound absorbtion, noise reduction and etc.

2. Review of the acoustic performance of noise barriers made of waste or plant-based materials

In order to ensure the principles of sustainability, environmentally friendly materials are increasingly used in the construction sector. Materials of natural origin, waste or composite materials are mostly used (Asdrubali et al., 2012). To improve acoustic comfort, organic, plant-based fiber materials with good sound absorption are often used. Fibrous, porous or granular wastes of various types also have good acoustic properties. These materials can be used in the production of noise barriers.

The acoustic performance of noise barriers made of waste or plant-based materials is reviewed.

2.1. Waste materials

Many researchers have investigated the acoustic potential of various waste or composite materials. Amarilla et al. (2021) performed an acoustic barrier simulation of construction and demolition waste. Scientists made blocks from construction and demolition waste and studied their sound absorption in an impedance tube. Based on the obtained results, the effectiveness of the noise barrier in the residential environment was modeled using the numerical simulation program SoundPlan. The results showed that this type of barrier is suitable for use in reducing traffic noise. This means that construction and demolition waste can be used to build noise barriers and ensure clean production principles (Amarilla et al., 2021). A similar study was conducted and the results were confirmed by Arenas et al. (2017). The goal of research was to produce a porous concrete product using construction and demolition wastes and fly ash-based geopolymer as binder. By mixing these components in a 1:2 ratio, a peak sound absorption coefficient of 0.7–0.9 is achieved. It was found that the created porous concrete showed better acoustic and mechanical properties than conventional concrete of the same thickness. It is concluded that construction and demolition waste can be recycled and reused for the production of noise barriers (Arenas et al., 2017). Concrete blocks made from construction and demolition waste were also proposed by Leiva et al. (2013). The researchers found that concrete blocks made from waste absorbs sound in the entire frequency spectrum better than concrete blocks made from traditional components due to the increased porosity of the concrete blocks (Leiva et al., 2013).

Arenas et al. (2020) conducted a study on porous concrete made from waste. The purpose of the study was to determine the possibilities of using this type of concrete for the production of a noise barrier. Mechanical properties, acoustic properties, physical properties and leaching properties were tested. The influence of the size and type of waste particles on the analyzed parameters was evaluated. It was found that the type of waste in the analyzed samples of porous concrete, when the size of the waste particles is the same, did not affect the sound absorption. Conducting sound absorption tests in an impedance tube, it was found that concrete with coarse and medium coarse aggregates absorbs sound well in the entire frequency band, and the highest absorption coefficient is at frequencies of 1000 and 4000 Hz. Concretes with fine aggregates, due to low porosity, had low sound absorption. After the research, the scientists concluded that all the examined waste can be used for the production of porous concrete (Arenas et al., 2020).

A lot of research has been done in order to find opportunities to use coal combustion bottom ash (Arenas et al., 2015; Ramzi Hannan et al., 2020). Arenas et al. (2013) developed panels made of coal bottom ash and Portland cement and investigated their acoustic properties. As in the previously described studies, the effect of aggregate particle size and porosity on absorption was observed. Coal bottom ash was divided into 3 different size fractions. Using the highest fraction of coal bottom ash particles in the samples, the best sound absorption coefficient was obtained. It is found that increasing the thickness of the sample increases sound absorption at low frequencies. The obtained results showed that coal combustion bottom ash could be recycled as highway noise barriers. The product made of 80% coal bottom ash showed similar properties to other conventional materials used in this application (Arenas et al., 2013).

Effective materials in sound absorbtion are tire waste: rubber and textile (Asdrubali et al., 2012; Ružickij et al., 2023; Wang & Du, 2020). In 1999, Pfretzschner & Rodriguez evaluated tire rubber granules as a suitable material to reduce traffic noise with the absorption (Pfretzschner & Rodriguez, 1999). Highest values of the absorption coefficient can be achieved using tyre waste grain sizes between 1 and 2 mm (Asdrubali et al., 2008). Wang and Du (2020) used recycled rubber granules for concrete production and studied its acoustic and thermal properties (Wang & Du, 2020). Recycled rubber granules is also used in the sonic crystal barriers (Dimitrijević et al., 2019).

Ceramic waste (Arenas et al., 2016), various types of textile waste (Rubino et al., 2019; Tiuc et al., 2016), cardboard waste (Asdrubali et al., 2016; Ouakarrouch et al., 2022) can also be used in noise absorbing barriers.

2.2. Plant-based materials

In order to reduce the use of synthetic materials in the production of barriers, Malaysian scientists proposed the use of environmentally friendly materials: coconut fiber and straw (Ismail et al., 2016). The natural coconut fiber and straw was mixed with the synthetic fiber and placed in the noise barrier. After examining the sample inside an anechoic chamber, a significant sound level reduction and a high acoustic potential of these materials were found. It was determined that using coconut fiber or straw fiber as a noise barrier, the sound level reduction was up to 15–20 dB in the frequency range from 3000 to 15,000 Hz. The researchers emphasized the acoustic potential of these materials and the need for further research (Ismail et al., 2016).

Singh et al. (2020) studied the acoustic properties of coconut fiber panels. It was found that the sound absorption and sound insulation of this material is low, but the material itself is very flexible, cheap and suitable for use as a composite material in noise barriers (Singh et al., 2020). Zulkifli et al. (2010) found that coconut fiber can be used as a composite material with a cotton base and a perforated plate, then the sound absorption can increase to 0.94–0.95 in the frequency range from 2600 to 2700 Hz. Composite panels of this type could be used in noise barriers, where sound absorption is required instead of reflection (Zulkifli et al., 2010). Halim et al. (2019) investigated the insulating properties of coconut fiber and developed a prototype barrier to reduce noise from metal stamping machines. During the research, it was found that after using this type of barrier, noise level has reduced by 17.2% (Halim et al., 2019).

Spanish scientists have chosen palm tree pruning waste to produce a noise barrier. They produced an eco-friendly 1:1 scale barrier prototype. The absorption properties of the barrier, insertion loss and sound transmission were investigated. Studies have shown good absorption properties of the barrier and the highest sound insulation of 23 dB was obtained by using palm tree pruning waste together with soil in a ratio of 1:1 (Gil-Lopez et al., 2017).

Recently, the acoustic properties of hemp fiber and the potential of this material in acoustics have been frequently studied (Liao et al., 2022; Santoni et al., 2019; C. Zhang et al., 2023; D. Zhang et al., 2022). Finnish researchers proposed using a barrier made of concrete and hemp fiber composite. The prototype was tested in a noise reduction chamber. It was found that this type of construction reduced the sound level by up to 46 dB (Prabesh, 2016; Protchenko, 2019).

Ouakarrouch et al. (2022) produced and studied ecological composite panels made from 60% of cardboard waste and 40% of natural fibers. The panels were made of reed, fig, doum, olive, bagasse, wheat straw and esparto. The sound absorption coefficient were in the range of 0.4–0.8, so it can be said that these materials could be used as sound absorbing elements in noise barriers (Ouakarrouch et al., 2022).

Currently, scientists are investigating not only the potential of plant materials to reduce noise, but also the plants themselves, which can be used as noise barriers. As a plant noise barrier, due to its fast growth and high density, bamboo is currently often studied. A 5 meter high and 6 meter wide bamboo barrier is said to be as effective as a 3 meter high solid, conventional barrier (van Leeuwen, 2016). The effectiveness of noise barriers from holly, bamboo and vi-burnum reached 4–6 dB(A), 3.5–4 dB(A) and 15 dB(A), respectively, while the noise barrier from willow reached 30 dB(A). The thickness of the researched plant barriers was 6 meters (van Leeuwen, 2016). Bamboo was also studied by Lagarrigue et al. (2013), they analyzed sustainable sonic crystal made of resonating bamboo rods (Lagarrigue et al., 2013).

Onder and Kocbeker (2012) investigated the effectiveness of roadside shrubs in reducing noise. The efficiency of the studied shrubs reached up to 6.3 dB(A), and this is most influenced by the distance from the noise source, the width of the plant barrier and the type of selected plants (Onder & Kocbeker, 2012). The effectiveness of plant barriers has been studied and confirmed by Nilsson et al. (2015). The use of low-height noise barriers near the road can reduce the sound level by an average of 4 dB(A). This type of barrier is the best at reducing high frequency sounds (Nilsson et al., 2015). Fang and Ling (2003) conducted a large study that examined 35 different types of plant barriers for noise reduction. It has been established that the effectiveness of the plant noise barrier can reach up to >10 dB(A), and the determining factors are density, height, length and width (Fang & Ling, 2003). Vegetative noise barriers were also studied by Lacasta et al. (2016), noise reduction of corn plants was analyzed by Puyana-Romero et al. (2021).

The great interest of scientists from all over the world in plant-based materials and plants as noise barriers shows the potential of these materials in the field of noise reduction and the need for further research.

Conclusions

During the study, the main trends in the use of waste and plant-based materials in acoustics and in the production of noise barriers were reviewed. The presented examples of the use of waste and plant-based materials show the great potential of these materials. It was established that researchers are currently trying to use construction and demolition waste, tire rubber waste and combustion ash waste for the production of barriers and acoustic materials. When reviewing the use of plant-based materials, we noticed that fibrous plant-based materials are mostly used for the production of noise barriers. The potential of plants as noise barriers is also being actively researched. Research by various scientists has shown that waste and plant-based materials used in the production of noise barriers are good future alternative to existing acoustic solutions.

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